# Opinion Page

## Opinion Page: *Science and the Desire to Understand*

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### Introduction

It might seem a commonplace to say that the aim of science is to provide understanding of the world around us. Scientists and laypeople alike will typically regard understanding as one of the most important and highly-valued products of scientific research and teaching. Indeed, science appears to be quite successful in achieving this aim: Who would doubt that science has given us understanding of such diverse phenomena as the motions of the heavenly bodies, the tides, the weather, earthquakes, the formation of rocks and fossils, electricity and magnetism, and the evolution of species? Climate scientists, who strive to understand the process of global warming and other climate changes, provide a contemporary example of the centrality of understanding as an aim of science. The main task of the Intergovernmental Panel on Climate Change (IPCC) is to assess progress in scientific understanding of the climate system and climate change, as can be gleaned from its 2007 report. In the one-page introduction of the technical summary of *Climate Change 2007: The Physical Science Basis* (IPCC, 2012), the terms 'understand' or 'understanding' are used nine times. Here is a typical passage:

> While this report provides new and important policy-relevant information on the *scientific understanding* of climate change, the complexity of the climate system and the multiple interactions that determine its behaviour impose limitations on our ability to *understand* fully the future course of Earth's global climate. There is still an incomplete *physical understanding* of many components of the climate system and their role in climate change. (IPCC, 2012; my italics).

But what does it mean to seek or to achieve such understanding? What exactly *is* scientific understanding? This is first and foremost a philosophical question, and one that has been addressed by philosophers of science in the context of the long-standing debate about scientific explanation. Wesley Salmon, one of the key figures in this debate, spent the greater part of his career developing a philosophical account of scientific explanation. As he emphasised in his essay 'The importance of scientific understanding' (Salmon 1998, pp. 79-91), the principal goal of scientific explanation is the production of *understanding* of events and phenomena. Salmon's own theory, focuses on causal explanations, highlighting the fact that understanding is often achieved by uncovering the causes of phenomena. While there are alternative philosophical views of how scientific understanding is attained through scientific explanations, most philosophers agree on the idea that understanding – whatever its precise nature – is a central aim of science.

The question of the nature of scientific understanding is also a historical question: to answer it we can do no better than look at how scientific research has actually produced understanding in the course of its historical development. Indeed, science as a historical phenomenon may be defined with reference to the notion of understanding: it is traditionally presumed that science was born in ancient Greece, when Ionian philosophers of nature – in particular Thales of Miletus and his school – first adopted what may be called a naturalistic approach to explaining natural phenomena: they abandoned the idea that nature is subject to the capricious will of supernatural gods and thereby beyond human comprehension, and instead assumed that observed phenomena can be understood in terms of natural causes and laws. This important change in the attitude towards nature has been emphasised, for instance, by the physicist Erwin Schrödinger. In his 1948 Shearman Lectures, delivered at University College, London, which were later published under the title *Nature and the Greeks*, he stated:

> The grand idea that informed these men was that the world around them was something that could be understood, if one only took the trouble to observe it properly; [...]. They saw the world as a rather complicated mechanism, acting according to eternal innate laws, which they were curious to find out. This is, of course, the fundamental attitude of science up to this day" (Schrödinger, 1996, p. 57)

The prospect of understanding forms the basis of most – if not all – Greek natural philosophy since Thales. It is, for example, fundamental to Aristotle's philosophical work. "All men by nature desire to know", reads the famous opening sentence of his *Metaphysics* in the well-known translation by W.D. Ross. In his introduction to Aristotle's philosophy, however, Jonathan Lear argues that Aristotle's words are better interpreted as referring to a desire to *understand*: "To have *epistèmè* one must not only know a thing, one must also grasp its cause or explanation. This is to understand it: to know in a deep sense what it is and how it has come to be" (Lear, 1988, p. 6). It was therefore the idea that humans can understand nature that sparked the development of science.

## Scientific understanding: diversity and disagreement

In a word, science is the fruit of our desire to understand. But we need to investigate and explicate the nature of the understanding that science can provide. A first question that may be asked in this context is: Are there universal, timeless criteria for scientific understanding? Even a cursory look at the history of science suggests that the answer is: no. As an illustration, I will sketch an episode from the history of physics in which discussions about understanding played a crucial role: the genesis of quantum mechanics in the 1920s, which involved heated debates about the intelligibility of this theory and the related question of whether it can provide understanding of the phenomena in the domain of atomic physics. This case shows that scientists' standards of intelligibility and understanding vary strongly – not only diachronically but also synchronically.

The first quantum theory of atomic structure was developed by Niels Bohr, who presented it in his famous papers of 1913 and 1918. It included an atomic model that was problematic in various respects – both empirically and conceptually – and in the early 1920s many physicists attempted to improve Bohr's theory. After a number of years when not much progress was made, two new, rival quantum theories of the atom appeared on the scene: in July 1925 Werner Heisenberg submitted a paper which contained the foundations of 'matrix mechanics', and in early 1926 Erwin Schrödinger published a series of papers in which he presented 'wave mechanics' as an alternative to matrix mechanics.

Heisenberg's theory was intended to describe only relations between observable quantities, such as the frequencies and intensities of spectral lines emitted by atoms; it did not provide a concrete picture or model of the internal structure of atoms. Thus, it was a highly abstract theory which, moreover, was based on a type of mathematics – matrix theory – that most physicists were unfamiliar with at the time. Schrödinger's wave mechanics, by contrast, suggested the possibility of a visualising atomic structure: his theory described the atom in terms of wave phenomena. Also, the mathematics of his theory was simpler and more familiar to physicists than that of matrix mechanics: it was based on wave equations, which were part and parcel of university physics teaching.

Immediately, proponents of the two theories engaged in intense, sometimes even emotional discussions on the question of which theory was superior. It was Schrödinger who brought the notions of understanding and intelligibility to the centre of the debate, claiming that his wave mechanics was much better in providing true understanding of the phenomena, over and above mere description and prediction. Schrödinger expressed a strong commitment to the view that visualisation is a necessary condition for scientific understanding: "We cannot really alter our manner of thinking in space and time, and what we cannot comprehend within it we cannot understand at all" (Schrödinger, 1928, p. 27). Accordingly, he argued, only theories that are visualisable in space and time are intelligible and can give us understanding of phenomena.

Schrödinger was not alone in this respect: many physicists supported the idea that understanding requires visualisation and space-time description. Therefore, according to Schrödinger, visualisability is a necessary condition for the intelligibility of a scientific theory. Wave mechanics is visualisable (or so Schrödinger suggested) and thereby intelligible. Matrix mechanics, by contrast, is not visualisable, and accordingly unintelligible. This was not merely a philosophical point: Schrödinger also argued that visualisable theories are more fruitful. Because of its visualisability and its mathematical structure, wave mechanics was more easily applicable to a great variety of physical problem situations. It was therefore more favourably received and – at least initially – empirically more successful than matrix mechanics.

The advocates of matrix mechanics maintained, however, that their theory could yield understanding as well, and they tried to refute Schrödinger's line of reasoning by arguing that intelligibility is not necessarily associated with visualisability. Wolfgang Pauli, who like Heisenberg was a member of Bohr's group, admitted that matrix mechanics was an unusual theory that might indeed appear less intelligible than wave mechanics. However, he claimed that understanding it was merely a question of becoming familiar with the new conceptual system of the theory. Pauli admitted that the demand for intelligibility is legitimate, but he stated: "it should never count in physics as an argument for the retention of fixed conceptual systems. Once the new conceptual systems are settled, they will also be intelligible" (Pauli, 1979, p. 188). In other words, when future generations of physicists are used to quantum mechanics, they will find it intelligible even though it is not visualisable.

The competition between the two theories ultimately led to their synthesis. On the one hand, Schrödinger's hope for a visualisable interpretation of quantum mechanics was not fulfilled: the visualisability of his model is limited because it does not represent atoms as waves in ordinary three-dimensional space but in a multi-dimensional Hilbert space. Heisenberg, on the other hand, abandoned his radically abstract approach and re-introduced visualisable notions, such as position and momentum of electrons, at the atomic level. The combination of matrix and wave mechanics led to quantum mechanics as it is accepted and taught today. With hindsight it is clear that Schrödinger's thesis that visualisability is a necessary condition for intelligibility must be rejected – there is no *a priori* relation between understanding and visualisation. Still, it does not follow that his ideas were completely misguided and worthless. History only shows that standards of intelligibility and understanding may vary and change. Moreover, the history of quantum mechanics shows that debates about understanding and intelligibility often stimulate scientific development.

Almost every physicist will agree that understanding is a key aim of science, but there appears to be strong variation in views about what is required for such understanding. The case of quantum theory illustrates this nicely. Even today physicists and philosophers debate the question of whether – and if so, how – quantum mechanics can provide understanding (the many different interpretations of the theory can be seen in this light). Of course, one might think that quantum theory is an exceptional case, being an esoteric, counterintuitive theory that applies to a remote domain of reality. Thus, Richard Feynman famously stated that nobody understands quantum mechanics. Of atomic behaviour he said: "Even the experts do not understand it the way they would like to, and it is perfectly reasonable that they should not, because all of direct, human experience and of human intuition applies to large objects" (Feynman, Leighton, & Sands, 1963-1965, vol. 3, p. 1-1). While quantum theory surely is a strange theory, the fact that scientists disagree about its intelligibility is not exceptional: the history of physics abounds with debates about the intelligibility of theories and criteria for scientific understanding.

## Conclusion: Lessons from the history of science

Historical case studies can illustrate various aspects of scientific understanding and inform a philosophical analysis of it. For instance, the relation between metaphysical worldviews and scientific understanding emerges clearly in the seventeenth-century debate about the intelligibility of Newton's theory of universal gravitation, and the subsequent development of physicists' views on contact action versus action at a distance in the eighteenth and nineteenth centuries. This case nicely illustrates how criteria for understanding may change in time, and how they interact with metaphysics.

Initially, Newton's theory was criticised because it failed to conform to the Cartesian intelligibility ideal of contact action; the idea of forces acting at a distance was unacceptable to most seventeenth-century physicists. The main reason was that it did not fit into the generally accepted metaphysical worldview of Descartes, which assumed that matter is passive and can affect other matter only by means of direct impact. But between 1700 and 1850 action at a distance rather than contact action and causal chains dominated the scientific scene and attempts to formulate theories of gravitation based on contact action were ignored. Only in the second half of the nineteenth century did contact action again become an acceptable explanatory resource (see De Regt 2017, Chapter 5, for a detailed analysis).

I conclude that philosophy of science should take the history and practice of science seriously, and should accordingly acknowledge the contextual nature of scientific understanding. As the physicist and philosopher Carl Friedrich von Weiszäcker observed in a conversation with Grete Hermann and Werner Heisenberg:

> One should remember that with the historical development of science the structure of human thinking also changes. Scientific progress does not only consist in our discovering and understanding of new facts, but also in that, again and again, we learn new possible meanings of the word 'understanding' itself. (Heisenberg 1969, p. 173).

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